Utilization of Established Protocol in Identifying Potential Sites for Small Farm Reservoirs in Quezon Province, Philippines Using GIS-Based Water Resources Assessment

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ABSTRACT

The determination of appropriate locations for irrigation development is essential to achieve optimum water use and land productivity. The conventional approach in identifying potential sites for irrigation projects is tedious and time consuming. A modern and reliable water resources assessment model is thus needed. A GIS-based water resources assessment model for identifying suitable sites for Small Farm Reservoirs (SFR) was developed for optimum water resource allocation and utilization in Quezon Province. The study is part of the Department of Agriculture-Bureau of Agricultural Research (DA-BAR) project on Identification of Potential Sites for Small-Scale irrigation Projects (SSIPs) in CALABARZON. Primary data collection was conducted through needs and design assessment questionnaires for SFR, and geo-tagging application using mobile devices. Location maps of existing SFRs and potential sites for development of other SSIPs in the province were also generated. The three factors considered in site suitability mapping of SFR were (a) average annual rainfall, (b) slope and (c) soil texture of the area. The developed methodology was found useful in identifying optimal locations for SFR development in Quezon Province. Based on the protocol established, of the total 455,144 hectares for SFR development in Quezon Province, 14% was classified as highly suitable, 80% were classified as moderately suitable, and only 6% were categorized as marginally suitable. Such information is vital for agricultural irrigation planning and development using SFRs.

Keywords: GIS-based mapping, water resources assessment, small farm reservoir (SFR), small scale irrigation projects (SSIPs)

INTRODUCTION

The agriculture sector utilizes 80% of the country's total water withdrawal with irrigation as the largest water user (Luyun, 2015). Irrigation is mainly used in rice production systems such that a typical flooded farm practice puts a very high demand for water. In 2018, Irrigated rice accounted for about 70% of the total harvested rice area and 75% of the total volume of rice production in the country (PSA, 2018). Food security for the more than 100 million Filipinos will depend on appropriate strategies and decisions to secure optimum water resources.

Quezon is the largest province under the CALABARZON Region with a total land area of 870,660 hectares (8,706.60 km2). It covers about 54% of the total land area of the region. It is characterized as having a rugged terrain with few plains, valleys and swamps. The estimated total irrigable area of the province is 25,873 ha with 77.39% irrigation development based on the National Irrigation Administration inventory (NIA, 2018). The NIA estimates of potential irrigable areas are based on a 0-3% slope only including areas less than 100 ha, except those very small "salt and paper" areas. Areas with slopes of between 3-8% and even up to 8-18% can be irrigated by small scale irrigation systems.

Considering only the 3% slope as a threshold for estimating potential irrigable areas could be misleading without considering the soil suitability, water resources availability, feasibility of transboundary transfers, built-up areas, flood-prone and high-devastation areas, and economic feasibility (Inocencio, 2015). As such, there is a need to continually assess surface water and ground water potentials for irrigation and other uses. This should be done to facilitate the proper identification and zoning of potentially irrigable areas by gravity systems (i.e., National Irrigation System [NIS], Communal Irrigation System [CIS], and SSIPs (such as SFRs, small water impounding projects [SWIPs], small diversion dams [DD], and spring development [SD]) or by pumps (i.e., Shallow tube wells [STWs] and low-lift pumps/ pump irrigation system open source [LLPs/ PISOS]). This would help the NIA and the Bureau of Soil and Water Management (BSWM) to delineate which areas should be irrigated by NIS, CIS, SFRs, SWIPs, and STWs or PISOS.

Food security could be attained by the provision of proper irrigation which could reduce the effects of rainfall variability and ultimately increase cropping intensity per year. Sustainable food production that can be expected through the optimal development of land and water resources, depends on the method of irrigation considered (FAO, 2003). The identification of suitable sites for irrigation development is an important step towards maximizing water availability and land productivity in rainfed areas. The traditional approach of identification of potential sites for irrigation facilities needs to be complemented by a more innovative approach to water resource assessment. This study focused on the development of a protocol using Geographic Information System (GIS)-based map for identifying potential sites for Small Farm Reservoir (SFR) in Quezon Province. The result of the study could serve as a decision support framework to identify optimal locations where SFR can be implemented effectively and efficiently in the country.

MATERIALS AND METHODS

Inventory and collection of available data

Site suitability analysis was done at a catchment scale and needed various information from different sources including climate, topography, soils, water source, and irrigation systems, among others. Secondary data were obtained from the different government and non-government agencies (e.g. National Water Resources Board [NWRB], National Mapping and Resource Information Authority [NAMRIA], BSWM, NIA, DA-Regional Office) and research institutions. A complete enumeration of existing SFR in Quezon was undertaken. Other data generated from the surveyed municipal sites were integrated into the existing datasets.

The NIS and CIS data of Quezon province were collected from the NIA Irrigation Management Office (IMO) of Quezon. The Provincial Development and Physical Framework Plan (PDPFP) of the province was given by the Provincial Planning and Development Office (PPDO). The monthly rainfall data from January 1981 to September 2017 were extracted from Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS), from which the

Table 1. Summary of secondary information requirement and corresponding sources for SFR and the other SSIPs.

INFORMATION REQUIREMENT	DETAILS	SOURCE
Base maps and DEM		NAMRIA
Climate	Monthly rainfall data	Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS)
Groundwater	Lithologic data (well logs)	Comprehensive Irrigation Research and Development Umbrella Program (CIRDUP); Local Water Utilities Association (LWUA)
	Ground water potential map	Mines and Geosciences Bureau (MGB); NWRB
	Piezometric water level or water table depth	CIRDUP
Irrigation System	Name, location (dam), river source, service area (boundary)	BSWM; NIA
Land Use/Cover Map		NAMRIA
Streamflow/ River flow Data	Historical data	NWRB; Bureau of Research Standards (BRS); Bureau of Design (BOD)
Comprehensive Land Use Plan (CLUP)/ Provincial Development and Physical Framework Plan (PDPFP)		Local Government Unit (LGU)
Road Network		Department of Public Works and Highways (DPWH)
River Networks		NWRB
Aquifer Lithologic Properties	Depth to the water bearing formation Aquifer thickness Presence/ absence of confining layer Thickness of confining layer	CIRDUP
Aquifer Hydraulic Characteristics	Transmissivity, storage coefficient	CIRDUP
NIA Irrigated Area		NIA
Inventory of SSIPs		BSWM, Regional Agricultural Engineering Division (RAED) – Department of Agriculture Regional Field Office CALABARZON

Source: Amongo, *et al.* (2018)

average annual total rainfall was generated, and the dry and wet seasons were identified. The rainfall data of each season were computed for further use in the study. The road networks for the whole province were acquired in DPWH. Table 1 summarizes the secondary information requirement and corresponding sources for SFR and the other SSIPs. The established protocol was particularly used for SFRs to validate its applicability in generating suitability maps for a given agricultural area.

The average annual total rainfall data were extracted from the CHIRPS, which is a quasi-global rainfall dataset with a spatial resolution of 0.05° and temporal coverage of about 37 years starting from 1981 up to present (accessed from ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0). The slope map was derived from the Digital

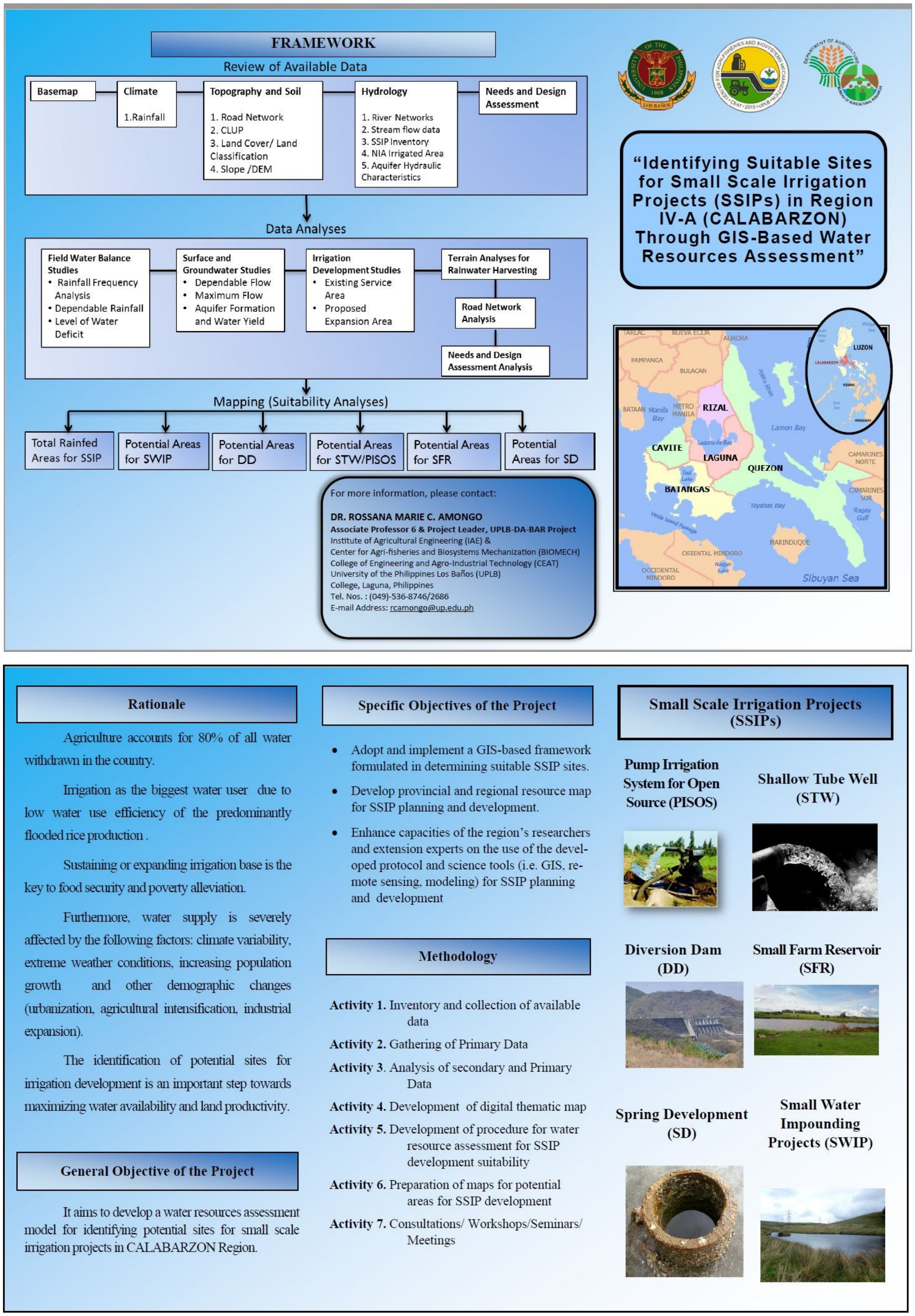

Figure 1. Project brochure.

Elevation Model (DEM) which in turn was generated from the IFSAR data provided by the AMRIA. Lastly, the soil texture data, which was a result of the collation of soil surveys conducted since the 1970s, was sourced from the BSWM.

Primary data collection and needs and design assessment (NADA) survey

Information, Education, and Communication (IEC) materials were produced to aid in information dissemination about the project (Figure 1). Survey instruments including needs and design assessment (NADA) questionnaires and datasheets for all existing SFRs, were formulated to aid in gathering information from the respondents and in measuring parameters of the SFRs. The questions in the survey form were made as simple as possible for easy and faster information collection from the respondents. Three (3) of the existing SFRs in Quezon Province, each with a corresponding farmer-respondent were utilized for the study.

Primary data collection through NADA survey was conducted to validate the obtained data from secondary sources, and to gather baseline information from the farmer-respondents on demographic profile and agricultural information. Primary data include the location, specification, service area, various uses, management of the SFR and problems encountered on the use of all existing SFRs in the area. Each SFR had a corresponding respondent, preferably the owner-user. If the SFR is being used collectively by the farmers' group, the leader of the group or a respondent knowledgeable of the SFR operation and management was considered as the respondent.

Training of Enumerators

Enumerators were trained on primary data requirements, geo-tagging, parameter measurements of SSIPs, and on how to administer the survey questionnaire with farmer-respondents. A total of 38 enumerators requested from the different Office of the Municipal Agriculturist of Quezon province were trained in April 2018.

Procedures employed in GIS

The average annual total rainfall, slope and soil texture data were reclassified using the criteria shown in Table 2 as the basis. The resulting raster thematic maps were then resampled to the same arbitrary resolution of 5 m and clipped to match the extent of the region using the associated algorithms in QGIS. The weights were applied in overlay analysis and the weighted scale average

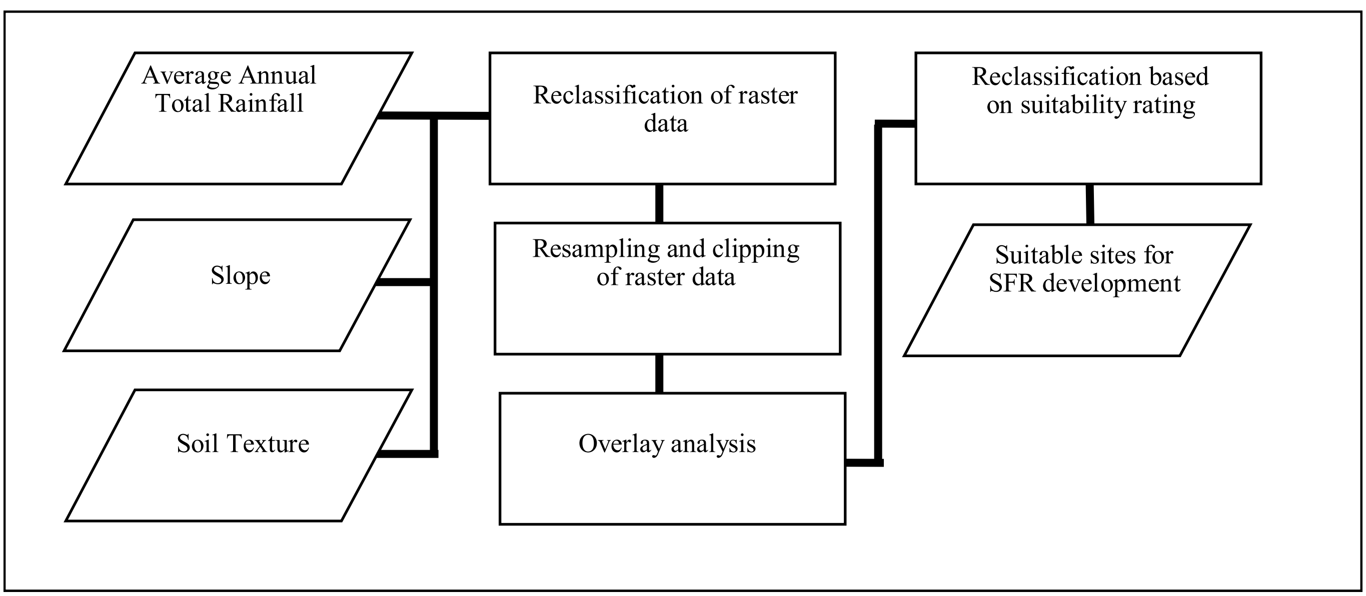

Figure 2. Flowchart of the overall process of site suitability analysis in GIS.

Table 2. Factors considered in suitability analysis and the corresponding suitability scales.

FACTORS	WEIGHT	DESCRIPTION	SUITABILITY SCALE
Average Annual Total Rainfall	40%	<1000 mm	1
		1000-1200 mm	2
		>1200 mm	3
Soil Texture	30%	Sand, loamy sand, silt, and sandy loam	0
		Silt loam	1
		Sandy clay loam and sandy clay	2
		Clay, clay loam, silty clay, silty clay loam, and loam	3
Slope	30%	>18%	0
		0-3%	1
		3-8%	2
		8-18%	3

was lifted from the resulting raster. Lastly, the raster containing the weighted scale average was reclassified to determine the suitability rating. Figure 2 shows the overall process of suitability analysis for SFR development in QGIS.

Generation of maps for suitable sites for small farm reservoirs

Tools for the generation of suitability maps

The open source application Quantum Geographic Information System (QGIS) 2.18 was used in the generation of the suitability maps for SFR. The Google Earth Engine (GEE) was used in the extraction of Sentinel 1 C-SAR data to be used in generating irrigated rice area maps.

Suitability Analysis

The three (3) vital factors for SFR suitability were the average annual total rainfall, soil texture and slope (DA-BAR, 2018). These factors were identified in the Review and Planning Workshop for the SSIP Research and Development Projects of the DA-BAR program on "Identifying Suitable Sites for Small Scale Irrigation Projects in the Regions through GIS-Based Water Resources Assessment" in BSP, BP International Hotel Makiling, Los Baños, Laguna. Suitability scales were assigned to each of the factors (Table 2). The suitability ratings and the corresponding range of weighted average are shown in Table 3.

Table 3. SFR Suitability ratings based on the range of weighted scale average.

SUITABILITY RATING	WEIGHTED SCALE AVERAGE RANGE
Not suitable	0-0.50
Marginally suitable	0.51-1.50
Moderately suitable	1.51-2.50
Highly suitable	2.51-3.00

Table 4. Summary of suitable areas for SFR development in Quezon Province.

SUITABILITY OF AREAS	AREAS (ha)
Highly suitable	63,135.51
Moderately suitable	366,240.15
Marginally suitable	25,768.69
Total Potential Areas for SFR Development	455,144.35

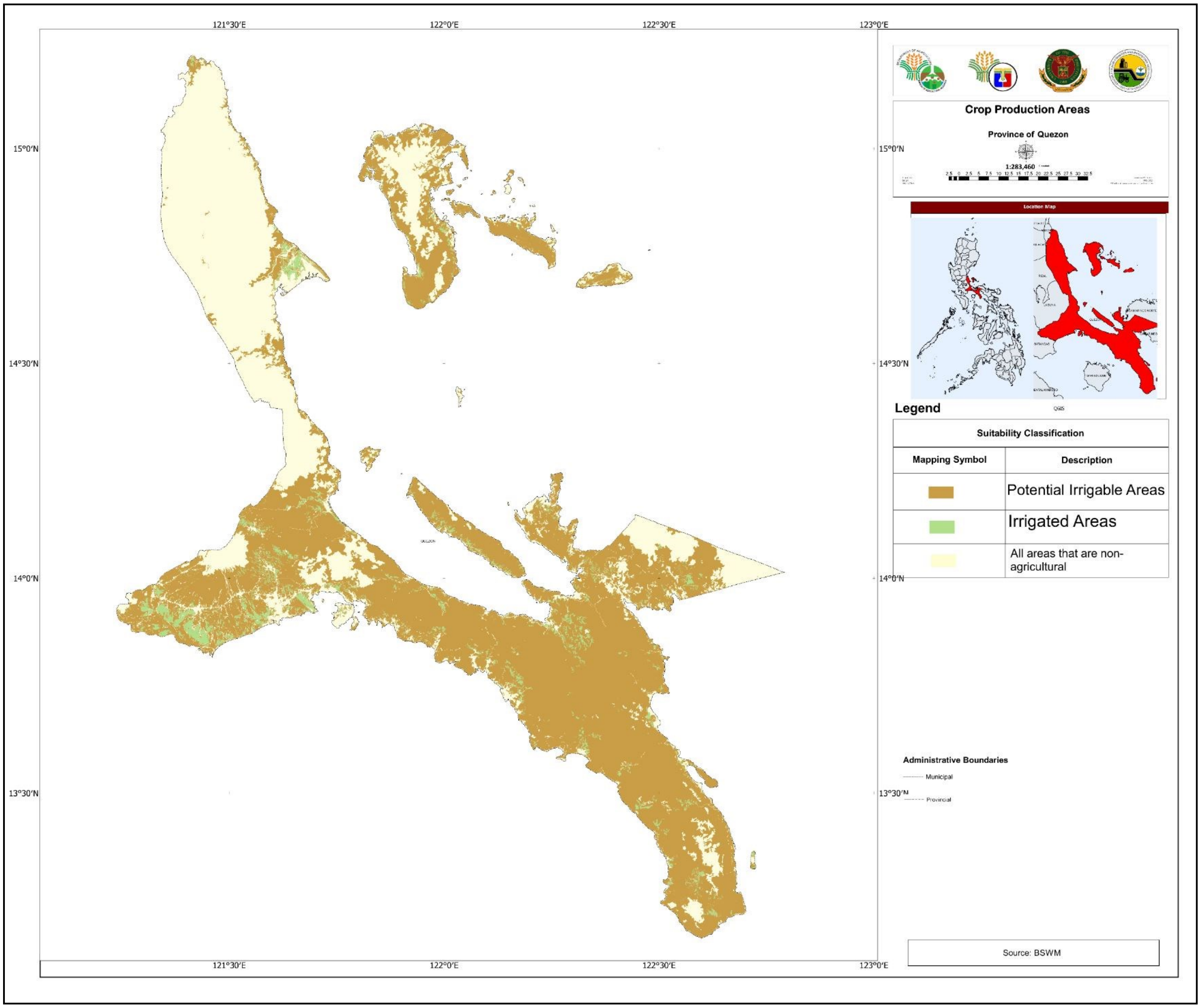

Figure 3. Crop production areas in Quezon Province, 2019

RESULTS AND DISCUSSION

Generation of maps for suitable sites for small farm reservoirs

The identification of suitable sites for SFR generally followed the protocol for the generation of maps for the SSIPs for the project in CALABARZON. The irrigated rice areas were mapped using SENTINEL-1A C-band SAR images where a threshold value was set to identify water bodies in the agricultural land area. If an entire series of the area has consistently low value, the area was identified as water. On the other hand, if the series has high value followed by a drop-in backscatter in the next figure, the area is identified as irrigated rice area. There are offsets in the planting dates in different areas. The total irrigated areas were the combined mapped areas at each image. High-slope areas were derived from the digital elevation models. These areas, along with water bodies, were eliminated from the total irrigated areas to further refine the map. Figure 3

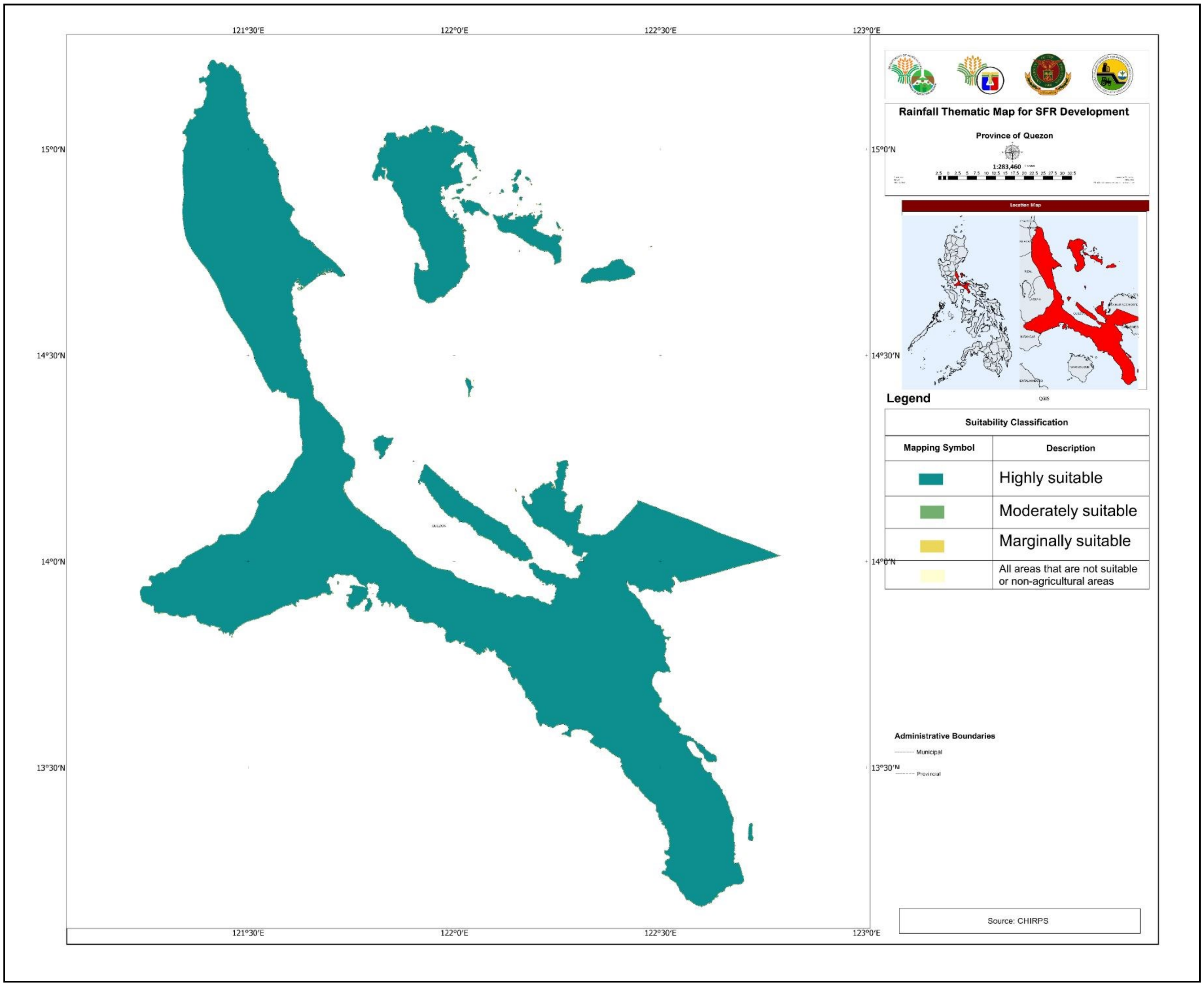

Figure 4. Annual rainfall map of Quezon Province, 2019

shows the total crop production area which includes the actual irrigated areas and potential irrigable areas based on 8% slope threshold. To determine the potential sites for SFR development in Quezon province, the actual irrigated areas were subtracted from the annual and perennial crop areas.

SFR Suitability Analysis

The three thematic maps, namely average annual rainfall (Figure 4), slope (Figure 5) and soil texture (Figure 6) were used to prepare the suitability map of SFR (Figure 7). Rainfall is the main water source for SFR especially during the dry season, while slope may define the flow of the water and the possible location of the SFRs. Areas with soil type classified as clay, clay loam, silty clay loam and loam were labelled as highly suitable. Clay soil has slow permeability which can hold large volume of water without much seepage and percolation losses.

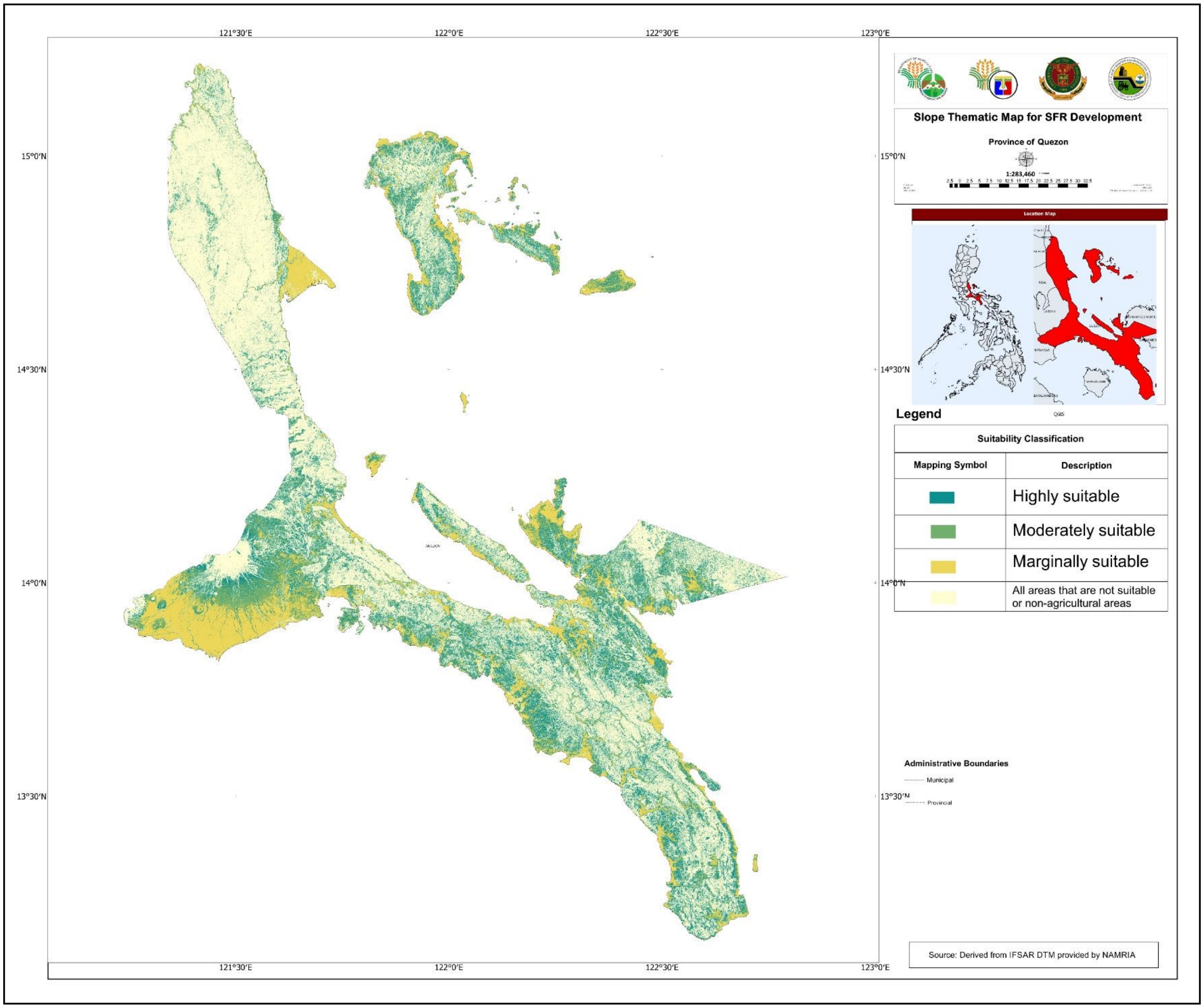

Figure 5. Slope map of Quezon Province, 2019

Figure 7 presents the suitability map of Quezon for SFR development. Furthermore, it shows that the surveyed SFRs, located in the municipalities of Lucena, Guinayangan, and Sariaya, were found to be in moderately suitable areas.

Based on the computed areas for SFR development, 14% of the total potential area are classified as highly suitable, 80% were classified as moderately suitable, and only 6% were categorized as marginally suitable. The areas of each classification can be seen in Table 4. A further refinement would be to delineate the areas with existing irrigation systems (NIS, CIS, SSIPs), the built-up areas, areas with restrictions (e.g. CADT, biodiversity protected areas).

CONCLUSION

With GIS-based water resources assessment, the effective determination of suitable sites for Small Scale Irrigation Projects (SSIPs) such as SFRs can be achieved. This is essential to provide optimum

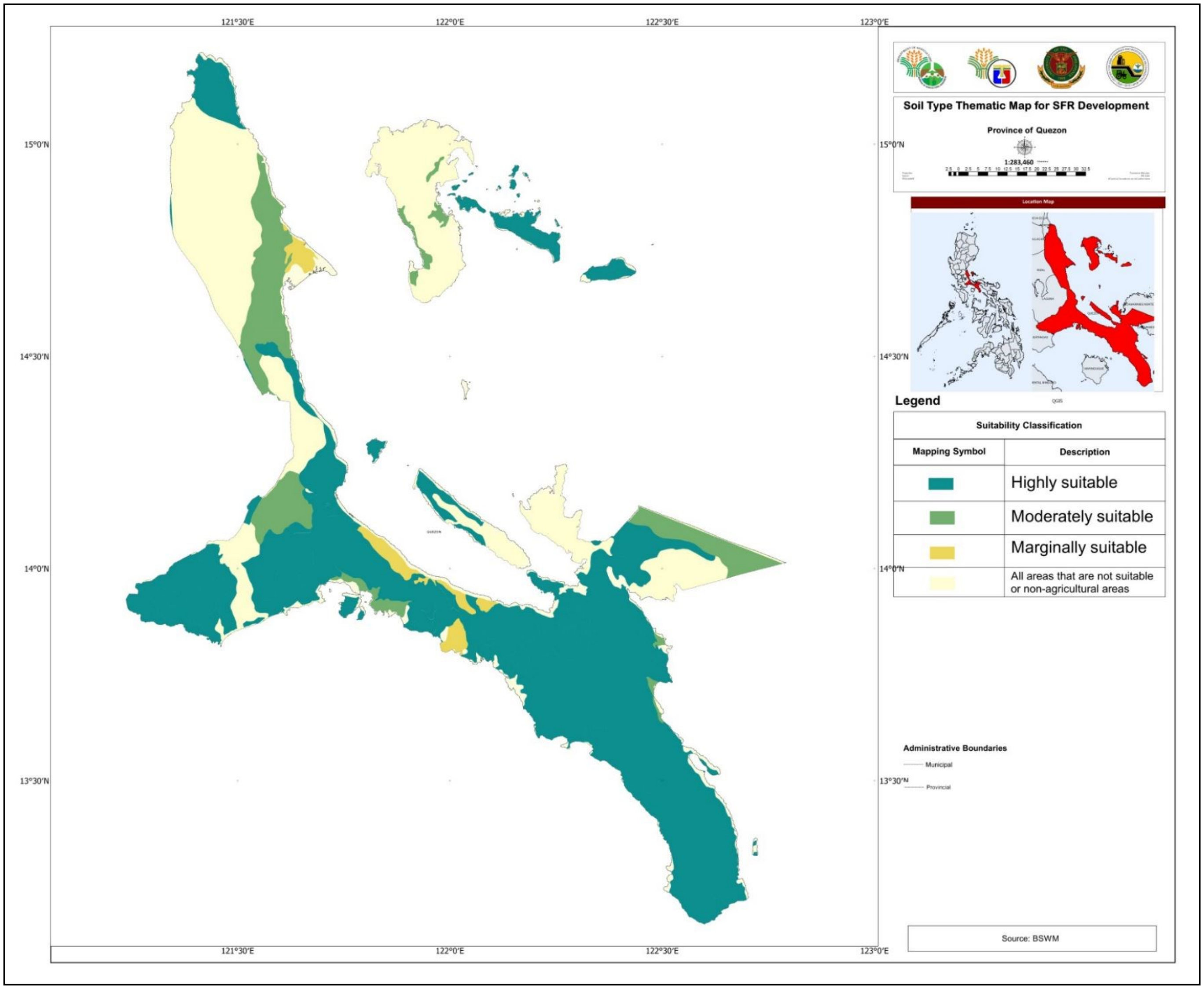

Figure 6. Soil texture map of Quezon Province, 2019

use of water and land resources. The development of water resource assessment maps for CALABARZON Region requires various thematic maps based on the respective suitability criteria of each SSIP. The developed strategies and methods of the study were proven to be useful and efficient in gathering and consolidating the needed information for map generation. The primary data gathering using NADA and through the help of LGUs' Agriculture Office fast-tracked the collection of data. The framework and protocols used for the suitability analysis of each type of SSIP provided promising results.

Based on the protocol used, of the total 455,144 hectares for SFR development in Quezon Province, 14% was classified as highly suitable, 80% were classified as moderately suitable, and only 6% were categorized as marginally suitable. Such information is vital for locating SFR for agricultural irrigation planning and development.

The developed GIS-based maps can be a valuable decision support framework to identify and optimize locations for the effective and efficient allocations of SFRs in the country for food sufficiency and security.

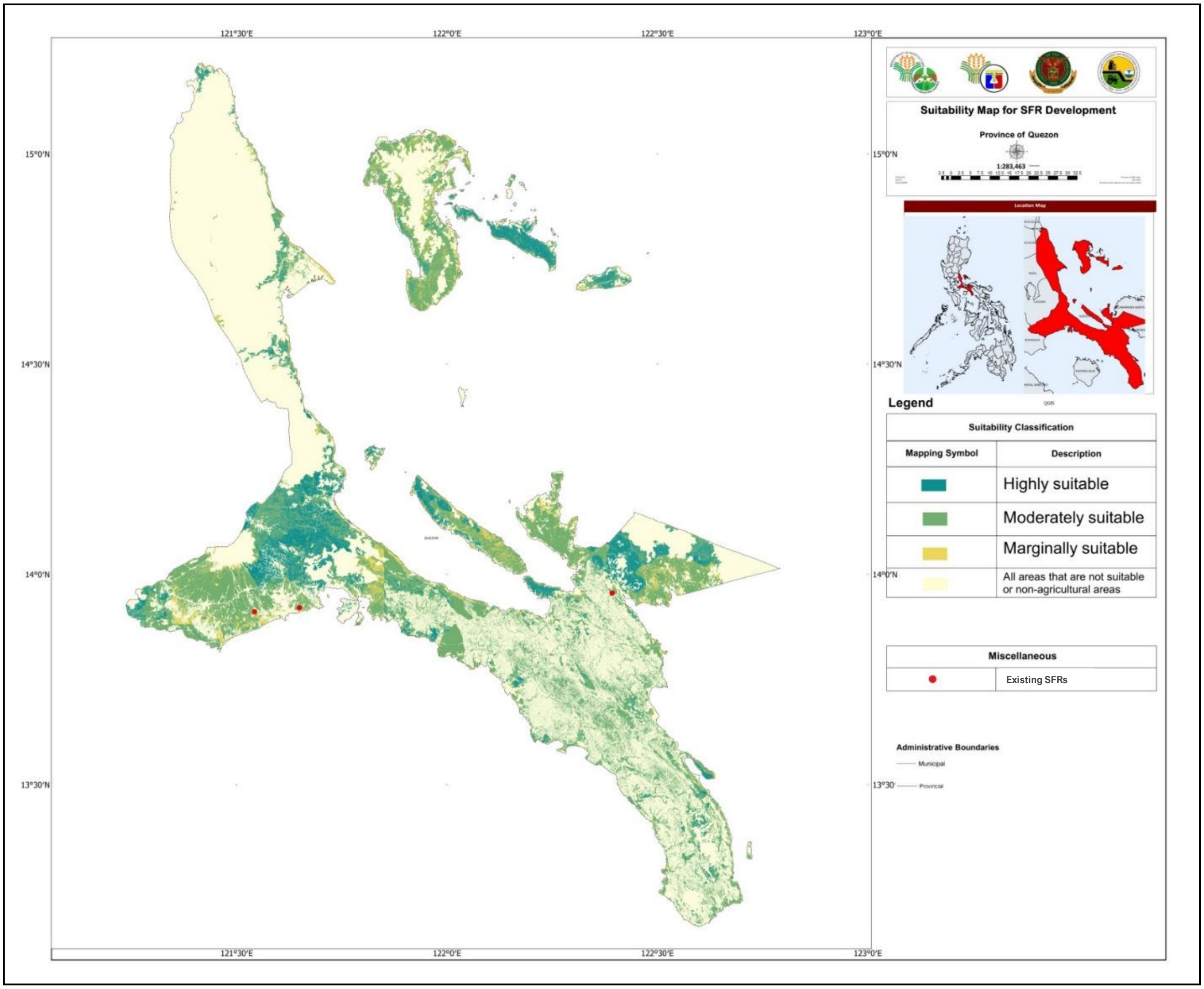

Figure 7. Suitability map of Quezon for Small Farm Reservoir, 2019

RECOMMENDATIONS

The protocol presented could be adopted for the identification of potential sites for small farm reservoirs in the other regions and provinces. However, it may be fine-tuned for location-specific problems and conditions, related to SFR identification in a particular region and respective provinces.

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A), Mines and Geosciences Bureau Region IV-A (MGB IV-A), Department of Agriculture Regional Field Office-Regional Agricultural Engineering Division IV-A (DA-RFO, RAED IV-A), National Water Resources Board (NWRB), National Mapping and Resource Information Authority (NAMRIA), the Sentinel 1 C-SAR Project, the Local Government Units of Cavite, Laguna, Batangas, Rizal and Quezon, and other agencies not mentioned. We would also like to thank the Municipal and City Agriculture Offices of CALABARZON.

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